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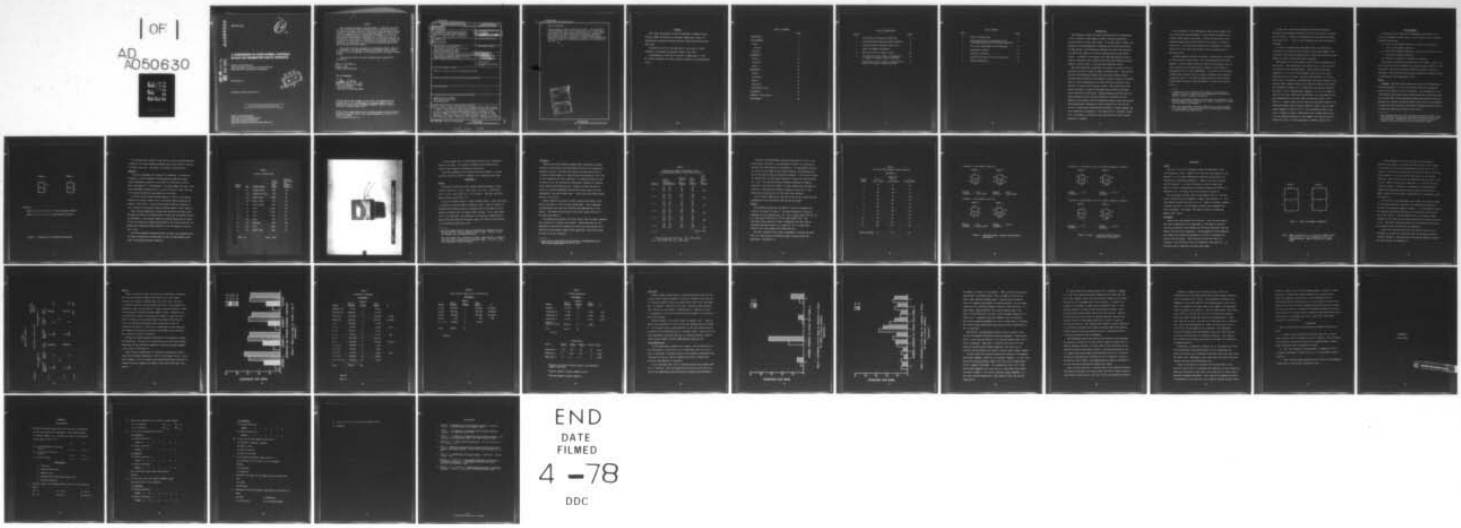

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A COMPARISON OF INTER-SYMBOL CONTRAST RATIOS FOR SEGMENTED DIGITAL READOUTS

HUMAN FACTORS BRANCH
CREW EQUIPMENT AND HUMAN FACTORS DIVISION
DIRECTORATE OF EQUIPMENT ENGINEERING

DECEMBER 1977

TECHNICAL REPORT ASD-TR-77-64

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Jane M. Kline

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FOR THE COMMANDER

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Twelve subjects viewed a Chicago Miniature segmented digital readout display to compare symbol legibility under two inter-symbol contrast ratio conditions - 4:1 and 2:1. Using two test lamps designated A and B, a series of test trials was presented under both conditions randomly intensifying the three horizontal segments of symbol A to determine the effect, if any, on symbol legibility. The stimuli consisted of numerical digits; digits 3, 5, 8, and 9 were presented at symbol A and digits 0-9 at symbol B. Performance data were

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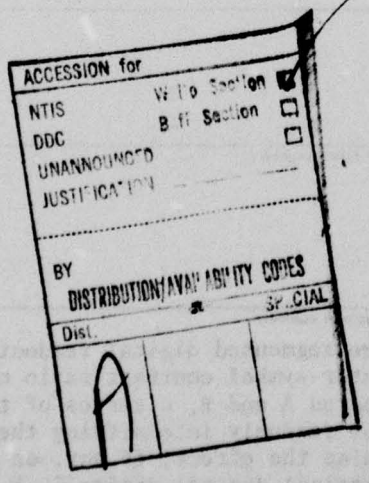
based on subject's digital readout error scores. From evaluation of the performance data, it was concluded that the 4:1 inter-symbol contrast ratio was significantly better than the 2:1 condition and that there was no apparent "aural effect" degrading performance under either condition. Additionally, "five" was significantly misidentified more often--primarily as a "nine." This identification error was attributed to insufficient distinguishing cues between the two digits.



FOREWORD

This report was prepared in the Crew Equipment and Human Factors Division (ENEC), Directorate of Equipment Engineering, Deputy for Engineering, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio.

Recognition is due Mr. Paul Kube and Mr. Jim Planet for their assistance in preparing the apparatus used in this study.

Acknowledgment is also due Lt Col Paul T. Kemmerling, Jr., and Mr. Richard Geiselhart for their technical assistance in preparing this report.

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INTRODUCTION

The engineers of night air combat during World War II precipitated a rash of studies of dark adaptation which ultimately established standards used for nearly twenty years. In the mid 1960's, however, the emergence of electroluminescent techniques and the resulting interest in high-contrast, low-illumination phenomena had caused some observers to question the adequacy of standard lighting practices and specifications. In addition, the necessity for displaying variously colored lights as instrument cues, combined with modern high intensity airfield lighting, further served to cloud the dark adaptation picture.

That dark adaptation is important can readily be attested to by the experiences of pilots flying in combat in Southeast Asia. Burdened with aircraft instrumentation packages featuring poorly matched display lighting, they frequently found themselves unable to obtain an acceptable level of overall illumination that would also permit sufficient dark adaptation to detect faint targets at night. These difficulties were usually traceable to specific instruments whose excessive brilliance formed "hot spots" in the panel. Assuming optimum conditions exist for dark adaptation and good contrast displays are available, aircrew members can effectively read low illuminated displays inside the aircraft while maintaining a vigilance for faint targets outside the aircraft. In fact, in many cases, particularly with respect to weapon systems, the above conditions are essential to the completion of a successful mission (i.e., the ability of aircrews to scan the horizon for other aircraft, missiles, or targets).

The requirement for low-illumination, high-contrast displays was also coupled with the requirement to avoid further overloading of an already crowded cockpit environment. During the last several years segmented lights[1] have gained attention as one method to compactly present data. One such display installed in a Department of Defense aircraft for use by Electronic Warfare Officers precipitated this particular study.

Although segmented numerals are compact, reducing space requirements, at lower intensity levels (below 1 fl) the disadvantages may become apparent. As the filament current and light level decreases, only the center portion of the filament heats, creating a "cold cathode" or "shrinking effect"[2] to the incandescents. In addition, the horizontal filaments may be fainter than the vertical filaments, thus creating a "washed-out effect."[3] The inter (between symbols) and intra-symbol (within symbol) contrast ratios may enhance or lessen these adverse effects.

---

1 A segmented lamp as referenced here consists of seven separate elements that may be selectively and independently illuminated to produce a variety of numeric characters.

2 Physically the element remains the same size, but perceptually, the visibly energized portion decreases in length, creating the illusion that the element is shrinking.

3 Under some conditions, an intense light source in close proximity to a less intense light source will tend to perceptually attenuate or even obscure the lesser source.

In this case, the display manufacturer performed experiments defining the intra-symbol contrast ratio as 2:1; this ratio is accepted by the Air Force. However, no documentation has defined the required inter-symbol ratio. It was to this undefined area that this study was addressed.

In order to determine the intra-symbol ratio, the manufacturer averaged the most intense, least intense, and one other segment; thus, this method could allow the manufacturer to selectively choose the third segment in order to comply with the 2:1 standard.

Additionally, a 4:1 inter-symbol contrast ratio is proposed by the manufacturer. The problem that could result from a 4:1 ratio will be illustrated by the following example. Assume symbol A has three segments of 2, 1.5, and 1 units intensity; then, the overall mean intensity level is 1.5 units. Note that this maintains a 2:1 intra-symbol ratio. According to the manufacturer, the mean intensity of the adjacent symbol (symbol B) may be four times as intense as the overall mean intensity of symbol A or, in other words, the average intensity may equal 6 units. Hypothetically, segments a, b, and c, of symbol B could be 8, 6, and 4 units and still maintain a 2:1 intra-symbol ratio and simultaneously be only four times as intense as symbol A (see Figure 1). However, while this is within the prescribed standards, the difference between the most intense segment of symbol B and the least intense segment of symbol A is 8:1. This averaging procedure could allow a filament to become a significantly more intense light source. If it is positioned adjacent to a dim segment, the results could be a "washed-out effect" or other degradation, causing a readout error.

THE EXPERIMENT

The purpose of this study was to investigate the effects of 4:1 and 2:1 inter-symbol contrast ratios. More specifically the following hypotheses were tested:

H_1 = The 2:1 inter-symbol condition is superior in legibility to the 4:1 inter-symbol condition.

H_2 = The uniform segment condition is superior in legibility to the intensified segment conditions.

H_3 = Symbol A is superior in legibility to symbol B.

The proposed experiment was accomplished in two phases. Phase 1 was used as a pilot study to determine the intensity levels required to yield appropriate error rates in digital reading while phase 2 tested the hypotheses. The following sections discuss subjects and apparatus which are applicable to both Experiments 1 and 2.

Method

Subjects. The same twelve subjects were used for both experiments. With one exception, all were in the military with aviator expertise either in the capacity of pilot or navigator. The exception was a non-rated military person with private flying experience; even though he was not military rated, he had experience reading instruments and displays. Subjects were required to meet the above criteria since the experimenter contends that their experience with flight instruments/digital readouts increased the operational validity of the study.[4]

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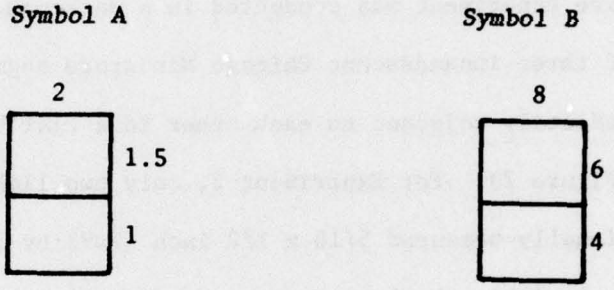
4 Not everyone agrees with this philosophy; however, the author feels that experienced subjects give the study more validity than totally naive subjects. Furthermore, using aircrew members provided an element of operational validity, not achieved with laymen.



Formulae:

Symbol A = (2 + 1.5 + 1)/3 = 1.5 units average intensity

Symbol B = (8 + 6 + 4)/3 = 6 units average intensity

Figure 1 Illustration of Potential Problem Area

All subjects were required to meet the eye acuity standards specified in AFM 60-1 for rated navigator personnel (near and far vision corrected to 20/20 in each eye). See Table 1 for subjects' personnel data.

Apparatus

The entire experiment was conducted in a darkroom. The apparatus consisted of three incandescent Chicago Miniature segmented lights mounted immediately adjacent to each other in a flat black vertical plane (see Figure 2). For Experiment 2, only two lights were used. Each lamp dimensionally measured 5/16 x 1/2 inch (7.93 by 12.7 mm); the size of the numeral within the lamp casing was (4 by 8 mm).

A vertical shutter device mounted directly in front of the display permitted the digital lights to be at peak power before presenting the display to the subject. A small box enclosed the shutter mechanics so only a portion of the shutter blade was visible through a small aperture.

Small fixation lights were located above and below the center digit providing the subject a reference point to reduce any "autokinetic effect." For Experiment 2, the fixation points were spaced between the two digits. A chin rest ensured the subject was oriented in the correct direction and maintained a constant 26 inches (66.04 cm) from the display to the subject's eyes.

A modified Commodore Minuteman 6X hand calculator was integrated with the digital display and a timing device so that the experimenter could insert the appropriate digital sequences.

TABLE 1

Subject Personnel Data

Subject Number	Age	Flight status	Total flying time (hrs)	Previous experience with segmented display
1	42	Command Pilot	3200	Yes
2	33	Commercial Pilot	500	No
3	33	Senior Pilot	1800	No
4	35	Senior Pilot	5200	No
5	38	Senior Pilot	2900	Yes
6	27	Pilot	1400	No
7	29	Pilot	2045	No
8	36	Pilot	4400	No
9	28	Pilot	1150	No
10	27	Navigator	800	Yes
11	32	Pilot	2800	No
12	34	Senior Pilot	3900	No
	Mean = 33		Mean = 2503	

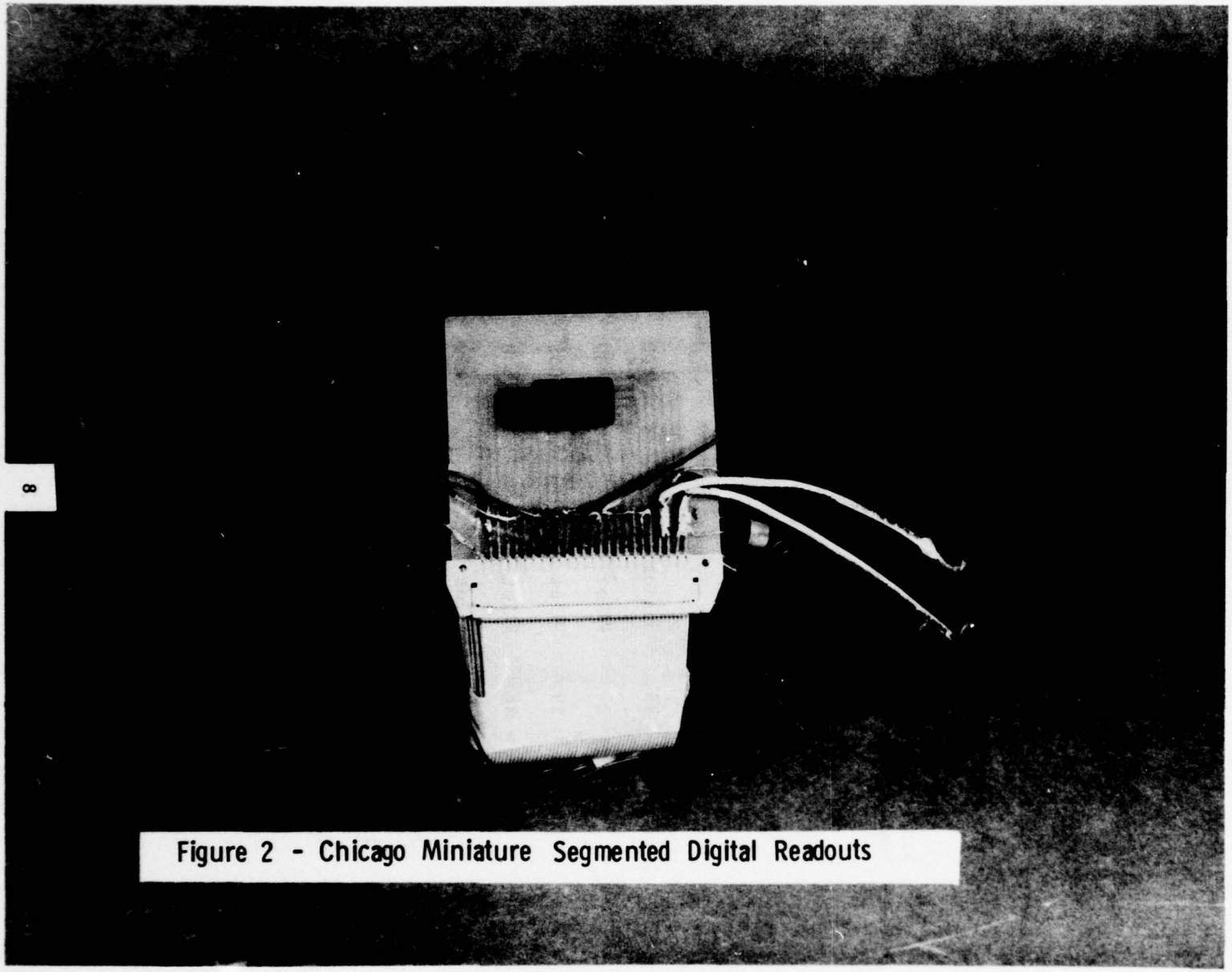


Figure 2 - Chicago Miniature Segmented Digital Readouts

A buzzer sounded prior to the beginning of each trial, cueing the subject to be alert. The subject's responses were recorded with a cassette tape recorder to be manually scored later.

Since the experimenter was located outside the darkroom, a two-way intercom allowed the subject's responses to be continually monitored.

EXPERIMENT 1

Stimuli

The stimuli consisted of three digital numbers presented at three intensity levels: (a) .05 fl (.2013 cd/m^2), (b) .07 fl (.2398 cd/m^2), and (c) .10 fl (.0342 cd/m^2) for .5 sec duration. The inter and intra-symbol contrast ratios were 1:1.[5]

Due to the inherent nature of these filament lights, a small difference in intensity was present between individual lamps. Each test symbol was photometrically measured when all filaments were lit and when the least number of filaments were lit (digits eight and one). Of the three lamps used in this experiment, the difference in intensity as measured with a Spectra 1980 Pritchard Spot Photometer (spot size .1mm) was seven percent or less between an eight and a one.

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5 The intra-symbol contrast ratio was determined by comparing the most intense and least intense segments within a lamp. In the 1:1 case, all segments were of uniform intensity.

The inter-symbol ratio compared the overall lamp intensity of symbol A with the overall intensity of the adjacent symbol. For the 1:1 case, both lamps were of equal intensity.

Procedures

Subjects wore dark adaptation goggles while completing a personal information questionnaire and being familiarized with the experimental equipment and task. Following this portion, subjects were seated in a darkroom without goggles to complete their dark adaptation; total time for dark adaptation was thirty minutes.[6] To familiarize subjects with the digital font, the experimenter individually displayed all numerals while verbally identifying each one. Subjects received 20 practice trials per condition beginning with the most intense light level and descending to the least intense level. A short rest was allowed between each set of 20 trials.

Having completed the practice trials, subjects were asked if they had any questions; if not, the test portion began. Sixty randomized counterbalanced test trials per condition were administered to each subject. The subjects were allowed a short rest between each set of 60 trials (see Table 2).

A microphone was attached to the chin rest so that the verbal responses were recorded by a cassette tape recorder. Before each test set, the experimenter instructed the subjects to turn on the tape recorder via a switch on the microphone; subjects were instructed to turn off the tape recorder at the end of the set.

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6 Thirty minutes dark adaptation was based on recommendations from Human Factors Engineering, McCormick, 1970.

TABLE 2

Experimental Design 1 Displaying the Six Counterbalancing Orders of the Three Conditions

Subjects	Light[a] intensity (footlamberts)		Practice trials per subject	Test trials per subject	Total test trials per subject
	(1)	.05	20	60	
n = 2	(2)	.10	20	60	
	(3)	.07	20	60	180
	(1)	.05	20	60	
n = 2	(2)	.07	20	60	
	(3)	.10	20	60	180
	(1)	.10	20	60	
n = 2	(2)	.05	20	60	
	(3)	.07	20	60	180
	(1)	.10	20	60	
n = 2	(2)	.07	20	60	
	(3)	.05	20	60	180
	(1)	.07	20	60	
n = 2	(2)	.05	20	60	
	(3)	.10	20	60	180
	(1)	.07	20	60	
n = 2	(2)	.10	20	60	
	(3)	.05	20	60	180
N = 12					Total = 2160

[a]The SI equivalent values are: .05-- .2013 cd/m^2, .07-- .2398 cd/m^2, and .10-- .0342 cd/m^2.

Typically, the experimenter instructed the subjects to turn on the tape recorder, thereafter, the experimenter inserted, via the digital keyboard, the three numerals to be displayed. The experimenter verified the accuracy of the input on the keyboard readout, then depressed the foot button which activated the shutter mechanism. A soft buzzer alerted the subjects prior to the shutter opening to display the three numerals for .5 sec. The subjects verbally responded repeating the numbers displayed or with the word "blank" for those numbers they were unable to interpret. Following each subject's response, another set of three numerals was presented until all 60 trials were completed.

Once a subject completed all 180 test trials, he was excused and the experimenter scored the answers from the tape recording.

Results

The dependent measure was the number of incorrect responses per condition as reported in Table 3. The mean percentage of incorrect responses for each condition was: (a) .05 fl (.2013 cd/m^2)--73%, (b) .07 fl (.2398 cd/m^2)--43%, and (c) .10 fl (.0342 cd/m^2)--25%. The individual scores depicted in Table 3 demonstrate the wide range of individual threshold levels; e.g., under the .07 fl (.2398 cd/m^2) condition the scores ranged from 14-99% incorrect.

The three intensity levels used in Experiment 2 provided the lower limit for constructing the individual symbol intensity levels for Experiment 2 (see Figure 3).

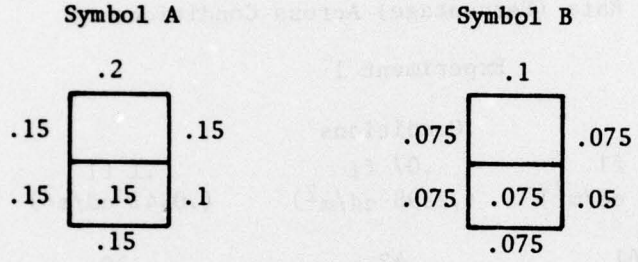
TABLE 3

Error Rate (Percentage) Across Conditions

Experiment 1

Subject number	Conditions .05 fl (.2013 cd/m^2)	.07 fl (.2398 cd/m^2)	.1 fl (.0342 cd/m^2)
1	61	42	30
2	51	25.5	13
3	90	52.5	42
4	68	43	30.5
5	81	28	13
6	98	86	59
7	60	16	09
8	79	30.5	18
9	86	42	17
10	99	99	50
11	59	32	13
12	40	14	10
Mean Percentage	73	43	25

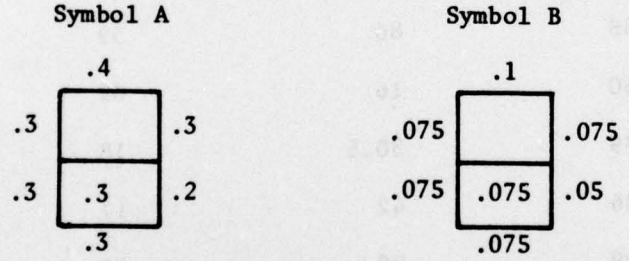
Condition 1, Inter-symbol ratio--2:1



Average intensity = .15 fl (.5139 cd/m^2)

Average intensity = .075 fl (.2569 cd/m^2)

Condition 2, Inter-symbol ratio--4:1

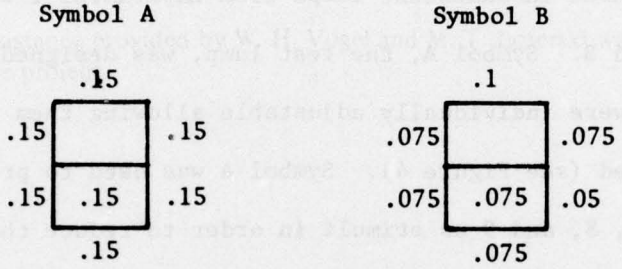


Average Intensity = .3 fl (1.0278 cd/m^2)

Average intensity = .075 fl

Figure 3. Individual Symbol Intensity Construction--Experiment 2

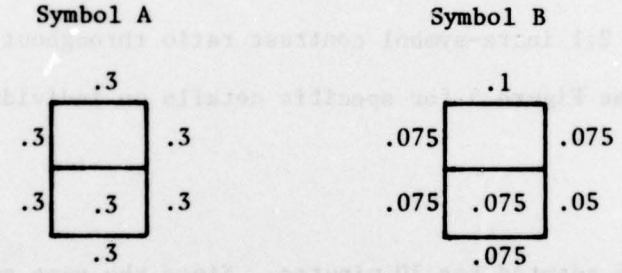
Condition 3, Inter-symbol ratio--2:1; Uniform segments in Symbol A



Average intensity = .15 fl

Average intensity = .075 fl

Condition 4, Inter-symbol ratio--4:1; Uniform segments in Symbol A



Average intensity = .3 fl

Average intensity = .075 fl

Figure 3 (contd). Individual Symbol Intensity Construction--Experiment 2

EXPERIMENT 2

Stimuli

Only two of the three incandescent lamps from Experiment 1 were used--designated A and B. Symbol A, the test lamp, was designed so that segments a, g, and d were individually adjustable allowing them to be intensified as required (see Figure 4). Symbol A was used to present only the numbers 3, 5, 8, and 9 as stimuli in order to reduce the number of possible combinations of intensified segments and numbers to manageable size. All digits (0-9) were presented in symbol B.

The intra-symbol contrast ratio of both symbols was 2:1 or for the control condition when all segments of symbol A were uniform, 1:1. The inter-symbol contrast ratio was 2:1 or 4:1. Symbol B retained a constant intensity level and a 2:1 intra-symbol contrast ratio throughout the entire experiment. See Figure 3 for specific details on individual segment light levels.

Procedures

Subjects were dark adapted for 30 minutes. Since the same subjects were used in Experiment 2 as in Experiment 1, the number of practice trials was minimized as each subject had sufficient familiarity with the display from his earlier experience. The experimenter briefly displayed each number while verbally identifying it in order to reacquaint the subject with the display. Then 10 practice trials were given for condition 4 and 10 practice trials for condition 3 (see Figure 3). If the subject had no questions, the test trials began.

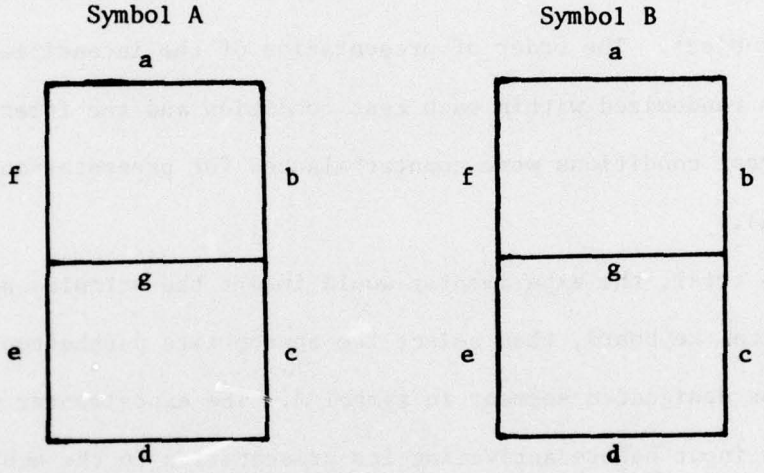


Figure 4. Symbol and Segment Designation

NOTE: Symbol A displayed 3, 5, 8, and 9 as stimuli either with segment a, g, or d intensified or with all segments uniform. Symbol B displayed all digits (0-9).

At the beginning of each set of trials, the experimenter instructed the subject to activate the tape recorder. Then a series of 160 random test trials was presented under either the 4:1 or 2:1 condition. Each subject received 40 test trials for each of the intensified segments (a, g, and d) and 40 test trials for the uniform condition. Each of the 40 trials was presented under both the 2:1 and 4:1 inter-symbol contrast ratio conditions, for a total of 320 test trials per subject. The order of presentation of the intensified segments was randomized within each test condition and the inter-symbol contrast conditions were counterbalanced for presentation order (see Table 4).

For each trial, the experimenter would insert the stimulus numbers via the digital keyboard, then select the appropriate pushbutton to intensify the designated segment in symbol A. The experimenter verified the keyboard input before activating its presentation to the subject with a foot switch. A buzzer sounded prior to the stimulus being displayed, after which the two numbers appeared via a shutter device for .5 sec. The subject verbally reported the two digits and the process was repeated until all 160 trials were finished.

A short rest separated the second test session from the first; thereafter, a second set of 160 test trials was presented under the alternate condition. After the second test period, subjects completed the questionnaire (see Appendix A).

TABLE 4

Experimental Design 2

Subjects	Inter-symbol contrast ratios						Total test trials per subject
	First Condition 4:1			Second Condition 2:1			
	Intensified segments	Practice trials	Test trials	Intensified segments	Practice trials	Test trials	
n = 6	a		40	a		40	
	d		40	d		40	
	g		40	g		40	
	none	10	40	none	10	40	320
	2:1			4:1			
n = 6	a		40	a		40	
	d		40	d		40	
	g		40	g		40	
	none	10	40	none	10	40	320
N = 12						Total	3840

Results

Figure 5 depicts the error rate across all experimental conditions. The vertical columns for symbol A show that the 4:1 inter-symbol contrast ratio yielded a substantially lower error score across all 4:1 situation symbol A was more readily perceived. This difference is significant, $p \leq .01$ (see Table 5). Again, as shown in Figure 5, there are even greater differences between symbols A and B. These data are also significant, $p \leq .01$, indicating that symbol A, under both the 4:1 and 2:1 conditions, was perceived better than symbol B (see Table 5). There is no significance between symbol B under the 4:1 and 2:1 conditions (see Table 6). This lack of significance is not unexpected since symbol B was identical under both inter-symbol ratio conditions and, therefore, served as a standard.

Although not readily apparent from Figure 5, the segments condition was significant. The source of the difference was tested using planned comparisons and was attributed primarily to difference between segments g and d, $p \leq .05$ (see Table 7).

Table 5 shows a significant R x D interaction indicating a differential effect between conditions 4:1 and 2:1 for symbols A and B. In the case of symbol A, the 4:1 condition was significantly better than the 2:1 condition, $p \leq .01$; whereas, for symbol B there was no difference (see Table 6).

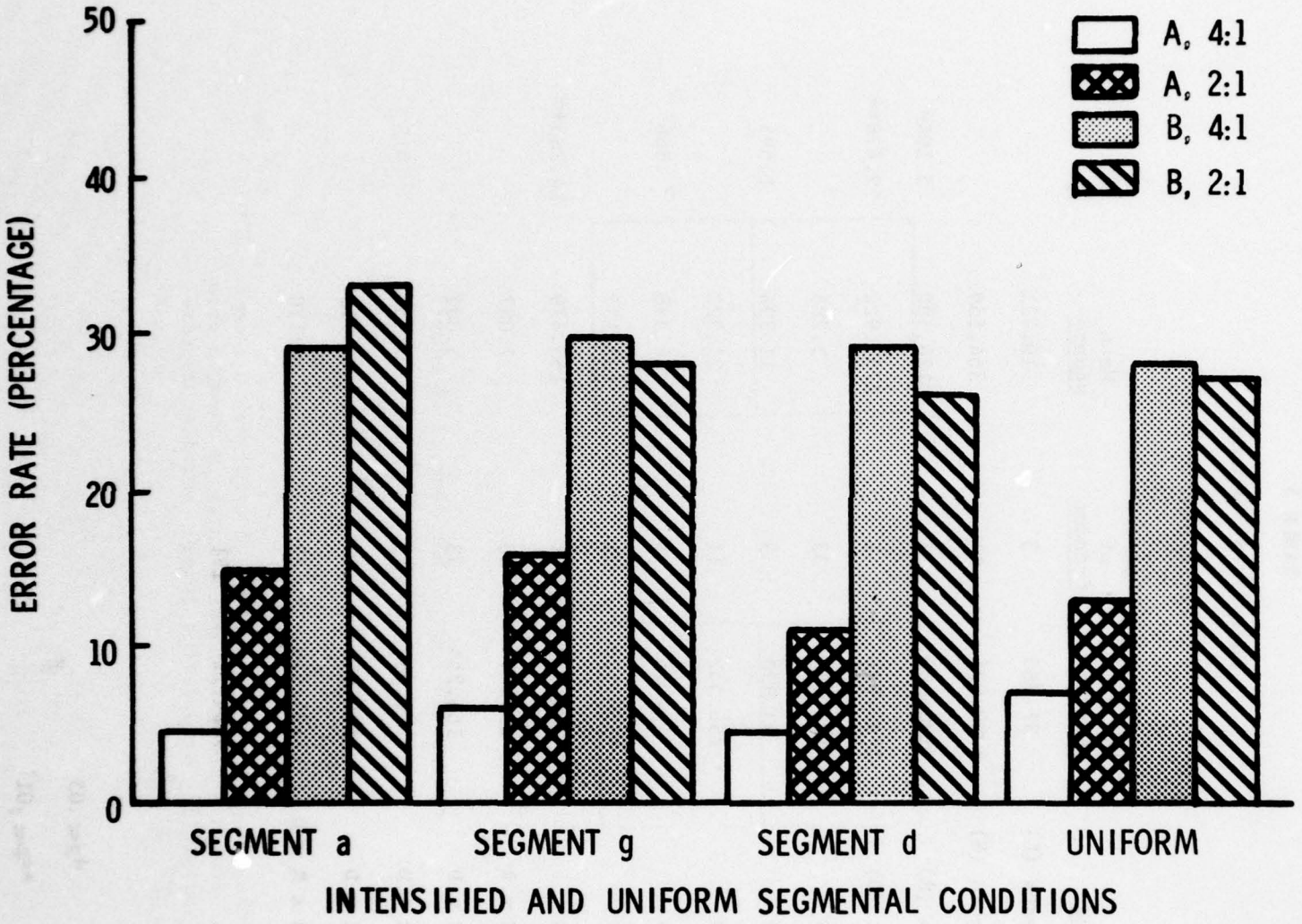


Figure 5 - Mean Error Rate for Symbols A and B
Experiment 2

TABLE 5

Analysis of Variance

EXPERIMENT 2

Source	Sum of squares	Degrees of freedom	Mean square	F
Segments (L)	31.265	3	10.421	
Subjects (S)	4009.931	11	364.539	
Ratio (R)	128.380	1	128.380	5.504*
Digit (D)	2767.922	1	2767.922	22.478**
L x S	108.530	33	3.288	
L x R	33.890	3	11.296	1.593
S x R	256.552	11	23.322	
L x D	13.015	3	4.338	.866
S x D	1354.508	11	123.137	
R x D	155.879	1	155.879	14.283**
L x S x R	233.895	33	7.087	
L x S x D	165.254	33	5.007	
L x R x D	10.057	3	3.352	.815
S x R x D	120.048	11	10.913	
L x S x R x D	135.640	33	4.110	
Total	9524.71	191		

*$p < .05$

**$p < .01$

TABLE 6

Simple Effects Test for R x D Interaction

EXPERIMENT 2

Source	Sum of squares	Degrees of freedom	Mean square	F
D @ R_1	2118.800	1	2118.800	210.820**
D @ R_2	805.000	1	805.000	80.090**
R @ D_1	283.600	1	283.600	28.210**
R @ D_2	.700	1	.700	.060
S x R x D	120.048	11	10.050	
Total	3328.14	15		

**$p < .01$

TABLE 7

Planned Comparisons

EXPERIMENT 2

Source	Sum of squares	Degrees of freedom	Mean square	F
Segments	(31.265)	(3)		
Comparison 1[a]	1.667	1	1.667	.510
Comparison 2[b]	12.087	1	12.087	3.675
Comparison 3[c]	17.511	1	17.511	5.324*
Segment x Subjects (Error)	108.530	33	3.288	
Total	139.78	39		

*$p < .05$

Coefficients

Source	Segment a	Segment g	Segment d	Uniform	$\sum c_i^2$
Comparison 1	-1/3	-1/3	-1/3	+1	1.333
Comparison 2	+1	-1/2	-1/2	0	1.500
Comparison 3	0	+1	-1	0	2.000

[a]Compared the uniform condition against the intensified segment conditions.

[b]Compared segment a against segments g and d.

[c]Compared segment g against segment d.

Discussion

Assuming symbol A was acting as a distracting bright source and was causing readout errors in symbol B, it would be expected that under the 4:1 condition symbol B should have significantly more errors than under the 2:1 condition. This was not the case. Therefore, this indicates that there was no inter-symbol "floodlighting" or "washed-out effect" as hypothesized. This will be analyzed more thoroughly in the questionnaire data section.

Further analysis of the data is shown in Figures 6 and 7. Figure 6 depicts the distribution of errors across the stimulus digits for symbol A. It is apparent that a large proportion of the error distribution is accounted for by misidentification of the digit "five." This is true for both experimental situations with the 2:1 condition showing a significantly greater number of errors (Mann-Whitney U test, $p < .05$).

Questionnaire data

On the questionnaire, subjects were asked to rate the difficulty of the task based on a scale from 1 to 5 (1 being very easy) for the 4:1 and 2:1 conditions. The mean rating for each condition respectively was 3.06 and 3.78 ($N = 9$). The 2:1 condition was rated a slightly more difficult task than the 4:1 condition.

It was anticipated that the 2:1 condition would be more legible than the 4:1 condition. While the quantitative data did not bear this out, some of the questionnaire data subjectively supported this hypothesis.

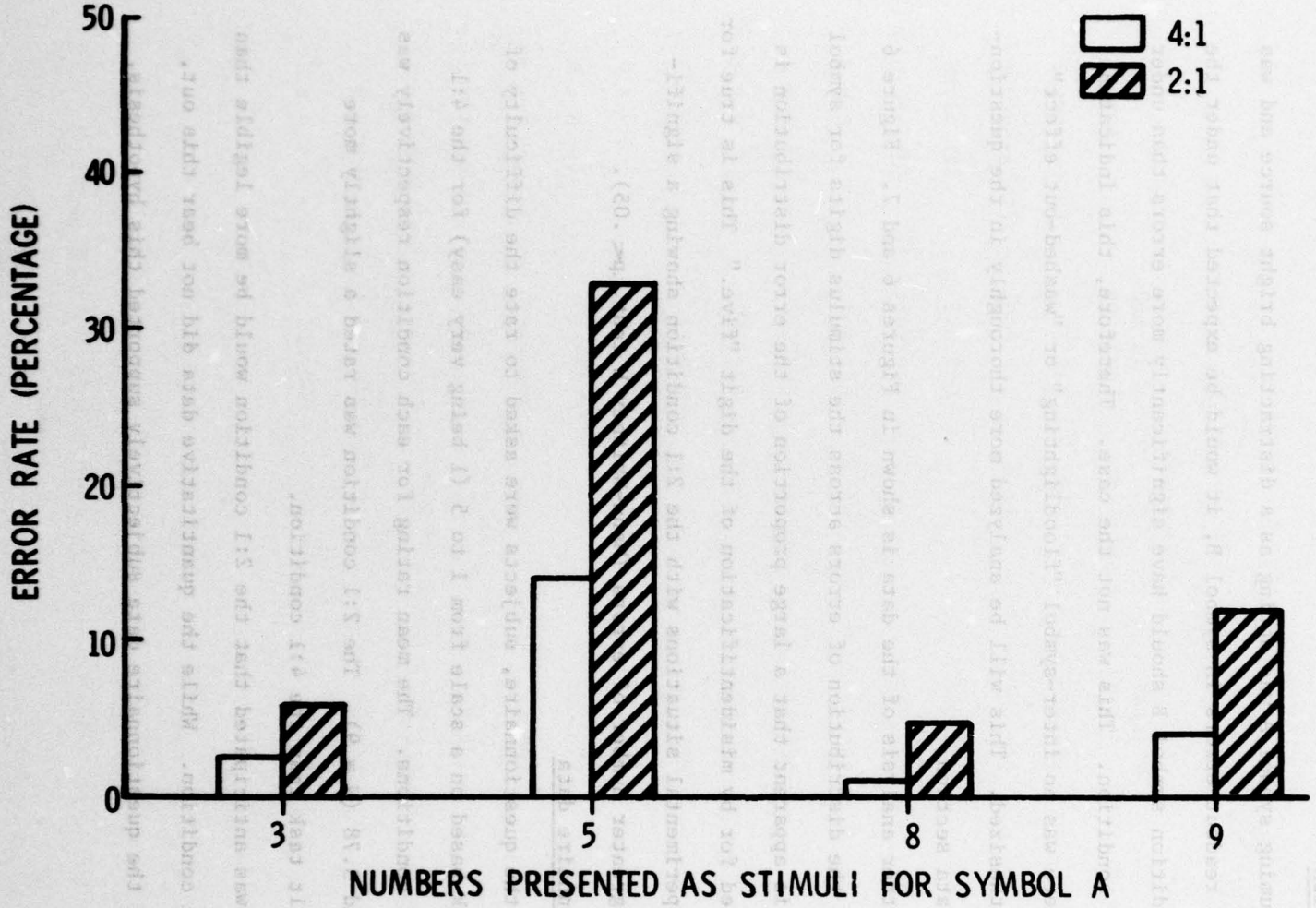


Figure 6 - Distribution of Error Means for Misidentity of Stimuli for Symbol A Across Conditions Experiment 2

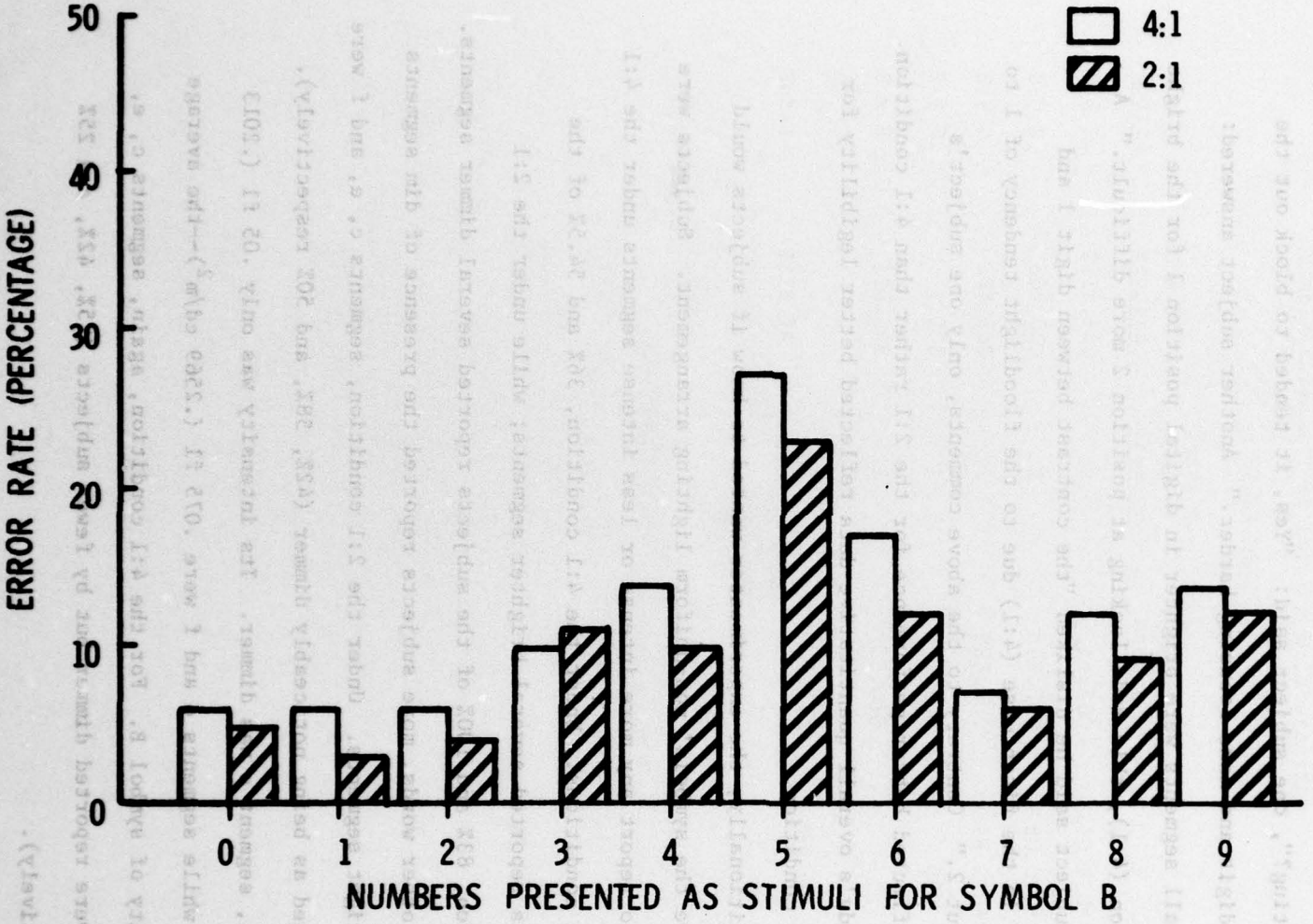


Figure 7 - Distribution of Error Means for Misidentity of Stimuli for Symbol B Across Conditions

Experiment 2

For example, in answer to the question: "Did you find the glare source distracting?", one subject said: "Yes, it tended to block out the second digit and make focusing harder." Another subject answered: "Since all segments were brighter in digital position 1 for the bright condition (4:1), this made looking at position 2 more difficult." A third subject said he disliked "the contrast between digit 1 and digit 2 in the first case (4:1) due to the floodlight tendency of 1 to drown out 2." Contrary to the above comments, only one subject's data reflected better performance for the 2:1 rather than 4:1 condition. The study's overall quantitative data reflected better legibility for the 4:1 condition.

Additionally, the experimenter wanted to know if subjects would perceive the symbols' non-uniform lighting arrangement. Subjects were asked to report any more intense or less intense segments under the 4:1 and 2:1 conditions. Under the 4:1 condition, 36% and 54.5% of the subjects reported several brighter segments; while under the 2:1 condition, 83% and 100% of the subjects reported several dimmer segments.

In other words, more subjects reported the presence of dim segments than bright segments. Under the 2:1 condition, segments c, e, and f were described as being noticeably dimmer (42%, 58%, and 50% respectively). In fact, segment c was dimmer. Its intensity was only .05 fl (.2013 cd/m^2) while segments e and f were .075 fl (.2569 cd/m^2)--the average intensity of symbol B. For the 4:1 condition, again, segments c, e, and f were reported dimmer but by fewer subjects (25%, 42%, and 25% respectively).

An "aural effect" was expected under the 4:1 condition. Segments c, e, and f were reported noticeably dimmer for both conditions; however, since segments e and f were not physically dimmer, one rationale could be that a "floodlight effect" was occurring. If symbol A was acting as a floodlight, it might cause a "washed-out effect" to the adjacent segments in symbol B, thus explaining why segments e and f were perceived as being dimmer when in fact they were not. However, if this were true then it would be expected that more subjects would perceive e and f as being dimmer under the 4:1 than 2:1 condition; this was not the case. This suggests that symbol A's greater legibility is a function of intensity level and/or increased symbol-to-background contrast and that while some subjects noticed a "floodlight effect," it was not reflected by their performance.

The discrepancy between the objective and subjective data regarding the presence or absence of an "aural effect" might be accounted for in terms of subject's workload. The only index of task difficulty was the subjective rating by the display viewers. As previously mentioned, the 2:1 condition was rated slightly more difficult than the 4:1 condition. If subjects were physically taxed more by the 4:1 condition in order to overcome the "aural effect," the experimenter was unable to determine it, as this study did not objectively measure this aspect.

Also, it may be that the 4:1 contrast ratio is the borderline between the absence or presence of an "aural effect" and that at higher intensity levels and/or contrast ratios this effect would have degraded performance.

Secondly, as reported in the results section, "five" was misidentified for both symbols more than the other stimuli--primarily "five" was mistaken for a "nine." The experimenter attributes this phenomenon to the fewer number of cues distinguishing a "five" from a "nine" as compared to the other digits; only segment b distinguished these two numerals (see Figure 4). The only other numeral that differs from a "five" by only one cue is a "six." Review of the confusion matrix for symbol B shows that "five" was misidentified as a "nine" 44% of the time and as a "six" 26% of the time under the 4:1 condition. Also, "five" was misidentified as a "nine" 44% of the time and as a "six" 39% of the time under the 2:1 condition. This phenomenon occurred only among these three numbers, since none of the other numerals had a high incidence of interaction confusion. This supports the rationale that the high error rate was the result of insufficient distinguishing cues.

Furthermore, as depicted in Figures 6 and 7, the majority of errors can be attributed to misidentification of "five" suggesting that corrective action such as training or increased viewing time would lower this error rate. Consequently, this would lower the overall error rate, thereby increasing the identification rate.

Finally, some mention is necessary of the implications of the results of this study to the problem area referred to in the introduction. Under the limitations of the study, it was shown that no "aural effect" operated to degrade performance. Also, there was no apparent detriment to performance as the result of an 8:1 disparity between the most intense

segment of symbol A and the least intense segment of symbol B. These data tend to suggest that overall intensity level and/or greater symbol-to-background contrast may be a more important factor in identifying display characters than a low inter-symbol contrast ratio. However, since only one type of segmented lamp was used for this experiment and since there are seemingly few standards pertaining to performance criterion for the many types of segmented lamps among manufacturers, the propriety of expanding these data to lamps other than Chicago Miniatures is problematical.

CONCLUSIONS

Based on the results of this study the following conclusions are made:

a. Digital readout performance was better under the 4:1 inter-symbol contrast ratio as compared to the 2:1 condition. This difference is attributed to increased legibility with increased symbol intensity and/or increased symbol-to-background contrast.

b. There was no apparent "floodlighting" or "washed-out effect" to degrade performance at either the 4:1 or 2:1 inter-symbol contrast condition.

c. "Five" was most often misidentified as a "nine;" this phenomenon is attributed to insufficient differential cues.

APPENDIX A

Questionnaire

APPENDIX A

Questionnaire

1. Using the provided rating scale, rate the level of difficulty of your task during this experiment. Do not limit yourself to cardinal numbers; i.e., you may use 1.65 for a rating that falls between 1 and 2, etc.

	4:1	2:1
(a) At the beginning of the test session	_____	_____
(b) At the end of the test session	_____	_____
(c) Overall rating	_____	_____

Rating Scale

1. Super easy
2. Required some effort
3. Moderate task
4. Required more effort than moderate task
5. Extremely difficult

2. How many errors, not counting practice trials, do you think you made?

(a) 0 (c) 6-10 (e) 21-40

(b) 1-5 (d) 11-20 (f) over 40

3a. During the experiment did you notice a glare source?

(1) 4:1 condition Yes ____ No ____

(2) 2:1 condition Yes ____ No ____

3b. If yes, can you pinpoint the source?

4:1 condition

(1) Digital position 1:

Segment a b c d e f g

(2) Digital position 2:

Segment a b c d e f g

2:1 condition

(1) Digital position 1:

Segment a b c d e f g

(2) Digital position 2:

Segment a b c d e f g

4. Did you find the glare source distracting?

Explain.

5a. Do you recall any of the digital segments being noticeably dim? If yes, identify.

4:1 condition

(1) Digital position 1:

Segment a b c d e f g

(2) Digital position 2:

Segment a b c d e f g

2:1 condition

(1) Digital position 1:

Segment a b c d e f g

(2) Digital position 2:

Segment a b c d e f g

5b. If yes, did the dim segment cause you to?

(a) Hesitate in making a response

(b) Make an error

(c) Both (a) and (b)

(d) None of the above

6. Do you think the digital light level was

(a) sufficient, (b) too dim, or (c) too bright?

Explain.

4:1 condition:

2:1 condition:

7. Was there any aspect of the readout digital display that you:

(a) Liked

(b) Disliked

8. How much do you think boredom contributed to the errors you made?

(a) None

(b) Very little

(c) Moderately

(d) A large percentage

9. Overall, did you like the type of display used?

10. Comments.

BIBLIOGRAPHY

1. Buschow, K. Readability of Digital Readout Displays. Marietta, Georgia: Lockheed-Georgia Co., November, 1966.

2. Gibney, T. K. Legibility of Segmented Versus Standard Numerals: A Review. USAF AMRL-TR-67-116, 1967.

3. Gibney, T. K. Legibility of Segmented Versus Standard Numerals: The Influence of the Observor's Task. USAF AMRL-TR-68-124, 1968.

4. McCormick, E. J. Human Factors Engineering. New York: McGraw-Hill Book Company, 1970.

5. Muick, C. Operational Evaluation of Filtered and Unfiltered White Aircraft Instrument Lighting. AGARD Conference Proceedings No. 26, 1967.

6. Poole, H. H. Fundamentals of Display Systems. Washington: Ratheon Company, 1966.

7. Spragg, S., & Rock, M. C. Dial Reading Performance As Related to Illumination Variables: I. Intensity. Rochester, New York: University of Rochester, 1948.

8. Woodson, W. E., & Conover, D. Human Engineering Guide for Equipment Designers. Berkeley: University of California Press, 1964.

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